Spring 2021

Natural User Interface Based American Sign Language Tutoring Program

Bryce J. Allen
The University of Akron, bja49@uakron.edu

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Honors Research Final Report

Bryce Allen

Faculty Advisor - Dr. Yingcai Xiao

Abstract

The COVID-19 pandemic has exposed a substantial shortcoming in the modern American educational system: there is a sufficient need for our educators to be trained in the practices required to provide an educational experience for their students that is as effective as in-person instruction. There exist already systems of online instruction for various academic subjects, such as math and the sciences. In the subject of linguistic studies, educational programs have been developed to evaluate student proficiency in both the written and spoken forms of the language in which they are studying. However, there exist few programs that can effectively provide a similar experience for students studying any variation of sign language. This report details the design process of a proposed system for an interactive online system for learning American Sign Language through the use of hand-tracking peripherals, such as Ultraleap's Leap Motion controller, and a course structure designed to teach the most commonly used words in American Sign Language through the use of time-spaced learning practices. This report details the course structure, the technical specifications for this system, and the methods through which academic institutions can effectively implement this system. ~~The end of~~

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Chapter 1: Introduction

1.1: Need

The National Deaf Center on Postsecondary Outcomes has identified that a significant proportion of deaf students in the United States achieve academic success to a lesser degree than their classmates with no form of hearing impairment. Of the individuals surveyed in their 2017 study, “Deaf People and Educational Attainment in the United States,” hearing individuals achieved greater success in every measured level of academic achievement, with the most substantial difference being a 15% gap in the general completion rate of a college bachelor’s degree in any field of academic study. If these results are filtered further to individuals aged 25 to 34, the gap in bachelor’s degree completion between hearing and deaf individuals increased to 18%, in favor of the individuals with no diagnosed hearing disorder. These figures demonstrate a genuine need for educational procedures that accommodate the special needs of students with impaired hearing abilities.

1.2: Objective

The objective of this project is to design a system to facilitate the learning process for students who possess significantly impaired hearing abilities and communicate through the use of sign language. For this project, our system will be initially implemented to interpret all hand signs, facial expressions, body language, and forms of eye contact through the context of American Sign Language (ASL) and will utilize these capabilities to teach and evaluate the student’s performance of the most common words used in American Sign Language discussions.

The platform will be designed with a series of frameworks to aid in the study of linguistic as well as non-linguistic subjects, such as biology, the social sciences, and engineering. The system will be designed in such a way that each student will be able to engage with the course material through the usage of a laptop or desktop computer and hand-tracking sensors, which will interpret their sign language gestures in areas where spoken language would normally be required.

1.3: Background

1.3.1: American Sign Language

As defined by the National Institute on Deafness and Other Communication Disorders, sign languages are defined as "[methods] of communication for people who are deaf or hard of hearing in which hand movements, gestures, and facial expressions convey grammatical structure and meaning." The study of sign language can be divided into several distinctive disciplines, generally based on regional differences in how a native language is spoken.

Despite this, American Sign Language (ASL) is a complete and natural language that is wholly distinct from the English language, as it is spoken in North America. According to the National Institute on Deafness and Other Communication Disorders, American Sign Language, as it is modernly expressed, is believed to have originated from a mixture of Langue des Signes Française or French Sign Language (LSF) and the local sign languages already present in North America centuries ago.

As it exists in its current form, American Sign Language possesses rules for pronunciation, word formation, and word order that differentiate it from not only various forms of spoken English, but other forms of Sign Language. As with any language, there exist

individual differences in expression, dialect, and rhythm, which can vary depending on the region in which the individual was raised. Words are spelled out using the user's hands and fingers, with each letter and number corresponding to distinct handshapes. As with the English language, there are twenty-six hand gestures for letters (A to Z) and ten hand gestures for numbers (0 to 9). Punctuation and various forms of inflection in American Sign Language are expressed in the form of facial expressions and bodily movements, such as raising eyebrows or tilting one's torso in various directions.

1.3.2: Hand Tracking

Increasing developments in the realm of virtual and augmented reality lead to an increased desire for control methods that can track body movements and gestures without the need for wearable peripherals. Initially released on July 22, 2012, Ultraleap (formerly known as Leap Motion, Inc.) released the first iteration of their hand tracking controller. This device, a sensor with the dimensions of 0.5x1.2x3 inches, can detect a user's hands through the use of two cameras and infrared LED technology. The Leap Motion Controller plugs directly into standard computers via a USB cable. The LEDs send out infrared lights at a roughly 150-degree radius, pulsing in sync with the framerate of the cameras. With each infrared pulse, the cameras send the coordinate data of where the user's hands are located back to the computer. This allows the sensor to effectively track the user's hands in real-time and generate precise virtual models of their hands, detailing the structure of their bones and joints in their fingers and wrists.

1.3.3: Time-Spaced Learning

Time-spaced learning (or simply spaced learning) is a learning method designed with the intent of minimizing the rate at which humans forget recently acquired information. The earliest

explorations of this field of memory science come from German psychologist, Hermann Ebbinghaus in his 1885 study, “On Memory.” Within this study, Ebbinghaus details his most famous discovery, the forgetting curve, a curve that describes the exponential decay at which people lose recently learned information. This curve specifies that the largest majority of memory decay occurs within the first twenty minutes of acquiring new information; the curve begins to level after the passage of one day. In opposition to the forgetting curve is the learning curve which dictates how quickly that we learn information. The most substantial increase in the learning curve occurs when you first learn new information and then it proceeds to even off exponentially from there.

Spaced learning capitalizes on Ebbinghaus’s studies by presenting information to students in intervals of time. After new information is introduced to the student, a period ranging from days, weeks, or months is allowed to pass before presenting the subject matter to the student once again. Variations in these time intervals are dependent on the content being studied and the audience who is attempting to learn this material.

The design of the spaced learning method is such that a series of information can be absorbed in short bursts over some time, providing a more efficient usage of time and enabling better memorization than taking large blocks of time to study.

1.3.4: Marketing Requirements

1. All required peripherals must be able to operate in any household environment.
2. The system must accommodate the special needs of the students using it.
3. The onboarding process for educators must be straightforward and succinct.

4. The onboarding process for the students must be simple and take a short amount of time to set up and effectively synchronize to the user.
5. The system must be affordable for academic institutions to implement promptly and maintain over time.
6. The system must be flexible enough to be used in the teaching and learning processes of subjects outside of the realm of linguistics.

Chapter 2: Tasks

The development of this project requires a number of interworking components in order to achieve our desired objectives. Among the necessary components needed are:

1. A system that can detect and identify the user's American Sign Language gestures in real time.
2. A facial recognition system that can detect and identify the user's facial expressions.
3. A visual recognition system that can detect and identify the orientation of the user's body.
4. A software component that can pair recognized facial expressions and body postures to the gestured sign and evaluate the appropriate context of the word being presented.
    a. A subsystem that can replicate these gestures back to the user in the form of digital hand and face models.
5. A programmable system that can take typed input from the instructor and translate that input into American Sign Language gestures.
    a. A subsystem that takes this translated input and presents it onscreen to the student in the form of digital hand and face models that can be displayed to the student during lessons.
6. A class system that can enable the instructor to record video lectures and have their gestures be identified in real-time to be paired alongside the video.
7. A deep learning system that enables the software to determine which gestures are being displayed based on previous training data.
8. A course system that enables instructors to organize the topics they wish to discuss over the course of the semester into individual modules

    a. A subsystem that takes the terms and subjects to be covered in each module and structures a lesson plan automatically through the use of a spaced learning model.

9. A translation component and can take visualized American Sign Language and translate it into plain text (and vice versa).

Chapter 3: Software Requirements

3.1: Training the Sign Recognition System

The American Sign Language identification system will assess the hand gestures performed by users through an artificial intelligence model. The Leap Motion controllers can detect subtle gestures by assessing the movements of individual joints and bones in the structures of both user's hands. These capabilities will allow the developers of the system to program a training data set containing the gestures for each letter and number of the American Sign Language alphabet. The system will then be manually fed test data showcasing each gesture of various different angles and at different rates, rating itself on its precision and accuracy in determining each of the gestures. Once given an adequate sample size of test cases, the system will be able to effectively assess gestures performed by individuals with varying degrees of fluency in American Sign Language.

3.2: Facial and Body Recognition System

To supplement the hand gestures being used to train the system's machine learning model, complementary systems will be used to train the system to identify distinctions in both facial expressions and body language. In contrast to the hand gestures, facial and body scans will be performed through the usage of cameras and facial recognition software.

3.3: Contextual Pairing System

Once datasets have been accumulated to assess hand gestures, facial expressions, and body postures, these individual models will be paired in a neural network with a new training set to identify the grammatical differences present within different combinations of gestures, facial expressions, and postures. Facial expressions and body language exist in American Sign

Language as “non-manual markers,” attributes that can determine the meaning of a phrase, in a similar manner to how changes in tonal inflection and pitch can change whether we interpret an English phrase as a statement or a question.

3.4: American Sign Language to Text Translation

Once the neural network is effectively trained in the grammar distinctions between words and phrases in American Sign Language, the system will be able to translate gestures into a text format in real-time. In conjunction with this, the system should also be capable of taking any text prompt presented to it and be able to visually represent the appropriate gestures, through the use of 3-dimensional graphic software. This system will enable the instructors to program unique translation questions that would otherwise not be easily replicated in a digital environment.

3.5: Curriculum Creation System

The system for creating academic curriculums will be designed to take advantage of spaced learning practices to optimize the students’ memory retention of the course material. As a result, courses will be divided into systems of modules, sub-modules, and prompts that are divided at the instructor’s discretion, based on how they intend to structure the content of the course. The instructor will determine the course material. The tutoring system will specify, based on the amount of content contained in each sub-module, as well as the performance of other students in that course, how much time is recommended for each student to study each sub-module. The system will emphasize frequent study through short periods of deliberate practice. The students will answer questions of various types and will be presented with sign language aids throughout their study, either in the form of video recordings from the instructor or digital

renders of hands and facial expressions designed to accurately represent different letters, words, and numbers in American Sign Language.

Chapter 4: Curriculum Requirements

Curriculums within the system must follow these guidelines:

- Each module must contain a series of different question prompts, grouped in the order that the instructor wishes to present them during the lectures.
- Each module must specify the desired dates for assessments and quizzes to be made accessible and due for the students.
- Each module must contain a video of the instructor performing American Sign Language or must contain a script log of the desired hand gestures to be performed as answers for each assessment
- The instructor must specify the minimum amount of time that they would like the students to spend on each day's study sessions.
    - Once each study session is started, each student is required to spend the minimum amount of time specified by their instructor and will be graded for the accuracy of their work once that time has been reached.
- The instructor must specify the minimum number of prompts that they would like the students to complete on each day's study sessions.
    - There will be an option to complete every question and an option to specify a specific number of questions to complete per session.

Chapter 5: Curriculum Design

Curriculums in the system are module-based and will evaluate the student's proficiency in the desired subject by utilizing the spaced learning model, based upon Hermann Ebbinghaus's discoveries. Instructors will have access to a curriculum creation page, which will allow them to build their courses, one module at a time. The modules can be categorized by title, tag, or course and will present the instructor with a series of forms, representing questions that they would like to ask the student. Questions will be available in various formats, including short answer, multiple-choice, true/false, listen and translate, video interpretation, signed response among other question formats. The instructor can group these questions into sub-modules, based upon the order in which they feel the students should learn the course material. Based upon the number of sub-modules, the system will generate a schedule of study sessions for the students that break up their study time into small periods that are evenly distributed over each week. This schedule takes advantage of Ebbinghaus's forgetting and learning curves by counterbalancing the periods shortly after learning new information where we are likely to forget a large percentage of what was learned with moments of regular rediscovery. In doing so, this learning methodology moves students further up the learning curve in the given subject, while also optimizing for the time they need to study in other subjects.

Chapter 6: Example Course Syllabus

Module 1: Letter & Number Signing

Week 1: Letters A-M

- Tuesday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
- Thursday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
    - Begin to finger spell a few words.
- Sunday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
    - Perform the gestures of a few words to form simple sentences.

Week 2: Letters N-Z

- Tuesday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
- Thursday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
    - Begin to finger spell a few words.
- Sunday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
    - Perform the gestures of a few words to form simple sentences.

Week 3: Numbers 0-9 & Test

- Tuesday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
- Thursday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
    - Begin to finger spell a few number sequences.
- Sunday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
    - Perform the gestures of a few words paired with numbers.

- Tuesday: Module 1 Exam

Module 2: Noun & Pronoun Signing

Week 4: Subject Nouns

- Thursday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
- Sunday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
- Tuesday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.

Week 5: Pronouns

- Thursday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
- Sunday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
- Tuesday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.

Week 6: Object & Location Nouns

- Thursday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
- Sunday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
- Tuesday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.
- Thursday: Module 2 Exam

Module 3: Verb Signing

Week 7: Action Verbs

- Tuesday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words

- Thursday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
- Sunday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.

Week 8: Linking Verbs

- Tuesday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
- Thursday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
- Sunday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.

Week 9: Helping Verbs

- Tuesday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
- Thursday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
- Sunday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.
- Tuesday: Module 3 Exam

Module 4: Adjective Signing

Week 10: Descriptive Adjectives

- Thursday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
- Sunday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
- Tuesday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.

Week 11: Limiting Adjectives

- Thursday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
- Sunday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
- Tuesday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.

Week 12: Limiting Adjectives (cont.)

- Thursday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
- Sunday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
- Tuesday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.
- Thursday: Module 4 Exam

Module 5: Final Exam Preparation

Week 13: Module 1 & 2

- Tuesday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
    - Perform the gestures of a few words to form simple sentences.
- Thursday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
    - Perform the gestures of a few words to form simple sentences.
- Sunday: Assigned study for 10 minutes.
    - Recognize visuals of each sign.
    - Gesture the sign from memory.
    - Perform the gestures of a few words to form simple sentences.

Week 14: Module 3

- Tuesday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.

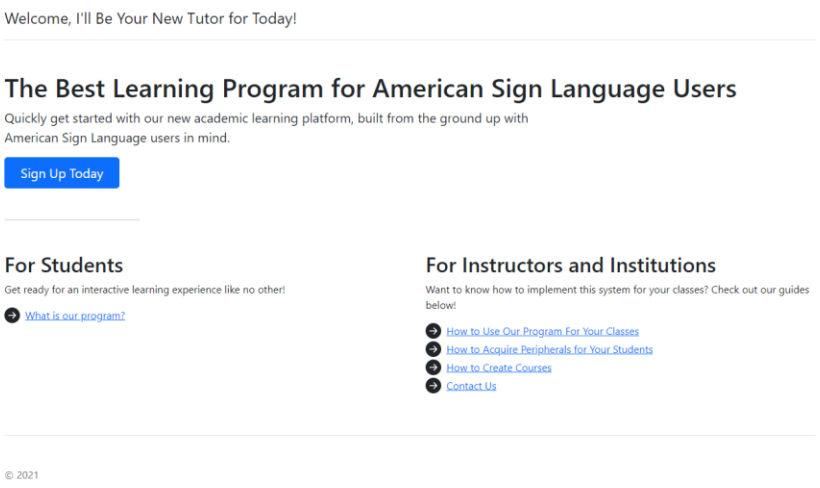
    - Perform the gestures of a few words to form simple sentences.
- Thursday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.
- Sunday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.

Week 15: Module 4

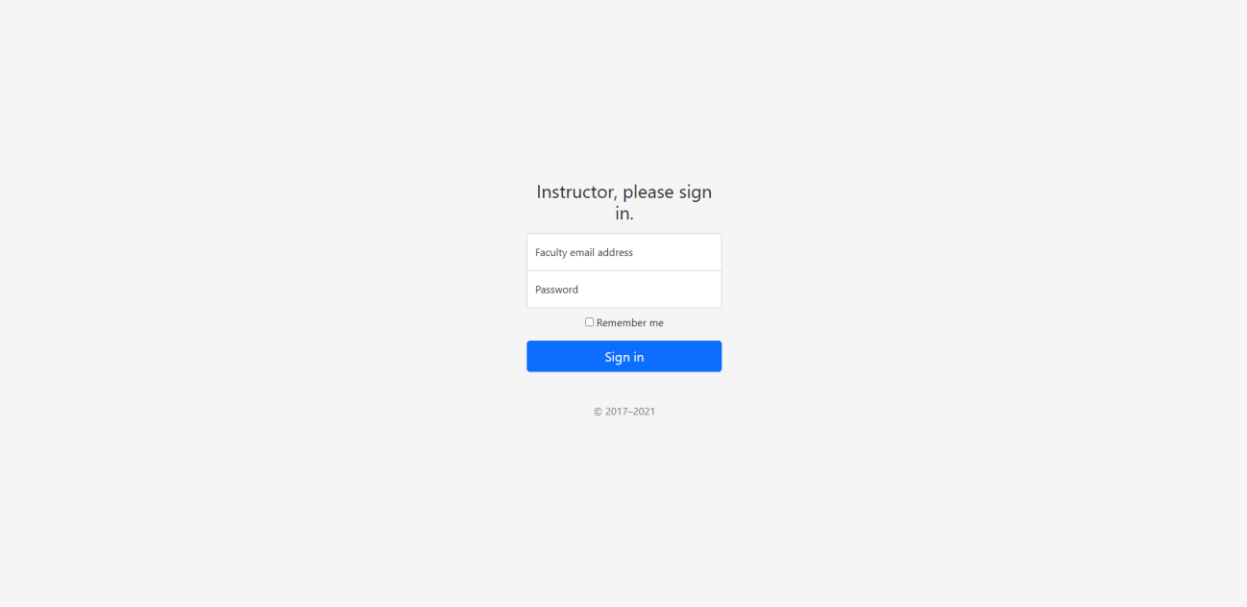
- Tuesday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.
- Thursday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.
- Sunday: Assigned study for 10 minutes.
    - Perform gesture sequences for specific words
    - Gesture the signs from memory.
    - Perform the gestures of a few words to form simple sentences.
- Tuesday: Module 5 (Final) Exam

Chapter 7: Mockup Website Application Screenshots

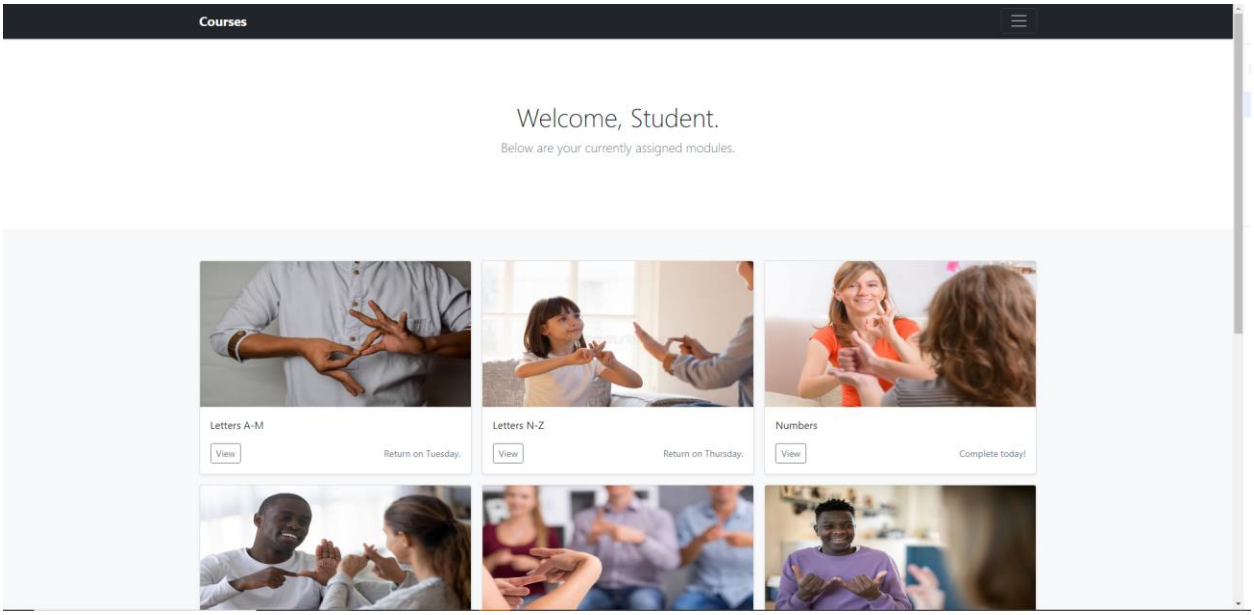
The following section showcases a series of screenshots for the early mockups of the application's website.



Home page.



Faculty sign in page.



Course home menu

Chapter 8: Hardware Requirements

The following is a list of the necessary hardware peripherals needed for each student to run the system:

- A laptop or desktop computer
    - Academic institutions who intend to implement this system must be capable of providing a laptop computer for each student using this system.
    - Must meet the minimum system requirements for Leap Motion use.
        - Operating System: Windows 7+ or Mac OS X 10.7
        - Processor: AMD Phenom™ II or Intel Core™ i3/i5/i7
        - Memory: 2 GB RAM
        - USB: at least two USB 2.0 ports
- Leap Motion Controller
    - Required for interpreting the specific hand gestures being performed by the students.
- USB ⅔ hybrid cable
    - Connects Leap Motion Controller to the student's computer
- A webcam
    - Academic institutions who intend to implement this system must be capable of providing a webcam for each student using this system, in case of the following applies:
        - The laptop computer that they possess lacks a webcam.
        - They do not currently possess a webcam for their desktop computer.
    - Will be critical for assessing secondary elements of American Sign Language interpretation, such as facial expressions and body movement.

Chapter 9: Budget

As the system currently stands, here is the estimated budget to implement the hand tracking education system*:

Product	Cost	Quantity
Leap Motion Controller**	$88.95	1
(Optional) C920 HD Pro Webcam	$79.99	1
(Optional) Dell Inspiron 15 Laptop Computer	$479.99	1
Mandatory Costs (per student):	$88.95	
Total Costs, including Optional Expenses (per student):	$648.93	

*Pricing figures shown exclude the cost of taxation and shipping. Also excludes the potential license key fees for our system software.

**Potential for waived fees per Leap Motion unit through participation in the Ultraleap Academic Program (see Licensing & Certifications).

Chapter 10: Licensing & Certification

As a legal requirement of working with Ultraleap's hand tracking devices, there are specific licensing requirements that must be met or to work with or distribute our proposed system.

Developers working on projects without the intent of commercializing them in the future can develop software applications using Ultraleap technology with the proper issuance of a developer license. The developer license is free and licensees gain access to special training and support from the support staff at Ultraleap, making this an effective position to start at in the early production phases for our proposed system. This support does not extend to engineering-related topics, including but not limited to the operation of the LED sensors. Also, any software developed by individuals or organizations under this license cannot publicly demonstrate their products nor can they sell any products or services with embedded Ultraleap tracking hardware or software.

For our system, a commercial license is required. In addition to the above provisions, Ultraleap offers engineering support for licensees by a separate agreement and enables the public demonstration and resale of solutions requiring their hardware or software. Commercial license rates are not publicly stated by Ultraleap and their team requires that you contact them with any inquiries to obtain a commercial license.

As a separate endeavor, Ultraleap provides an academic program with the intent of offering greater collaboration with academic and scientific institutions interested in using Ultraleap hardware and or software in their programs.

As it relates to the system proposed in this report, the development team of our system would have to obtain a commercial license to sell and distribute access to our system with the

option of potentially bundling Leap Motion controllers with each purchase of a software license key. As an option, our team could suggest to interested institutions that they inquire about becoming a partner of the Ultraleap academic program and negotiate the means through which they can obtain access to the surplus of Leap Motion controllers required for their students for a potentially discounted rate. In the process of doing so, our team could provide a bundle of license keys for our system at a reduced cost to partners of the Ultraleap Academic Program. By undergoing this process, it may reduce the barrier of entry for academic institutions interested in using our system to improve the academic experience of their deaf or hard of hearing students.

Chapter 11: Conclusion

The system proposed above has yet to be fully implemented, due to the time and resource constraints of the current team involved. The initial planning phase for the project lacked the structure and level of clarification offered by the final report, as it is currently being presented. A substantial proportion of my time was aimed towards individual research and idea formation for the system described above. With a more thorough roadmap being developed earlier on, a proper prototype could have been developed, utilizing the Leap Motion Controller to teach some early aspects of American Sign Language, such as the proper signage of each gesture and the methods of punctuation. Overall, greater adherence to establishing structure and more consistent communication with Dr. Xiao, through entirely my efforts, would have been instrumental in the completion of this project. The possibilities that hand-tracking technology has to offer the academic community are without limitations. Ultimately, I hope that information within this report provides an adequate framework for others to build off of what was established here.

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